# In tune with light

## Physicists use lasers to synchronize microscopic oscillators that act like the pendulums of clocks

PUBLISHED IN FEBRUARY - 2013

After suspending two pendulum clocks side by side from a wooden plank in 1665, the noted Dutch scientist Christiaan Huygens observed that the clocks soon began ticking in unison, even if the pendulums initially swung out of sync. The experiment impresses us even today, although how spontaneous synchronization of clocks works is no longer a mystery (a search for "*synchronization*" on YouTube turns up several interesting demonstrations of this phenomenon). Physicists can now accurately calculate how the clocks influence each other by means of mechanical vibrations exchanged through the board that eventually force the clocks to oscillate in the same manner.

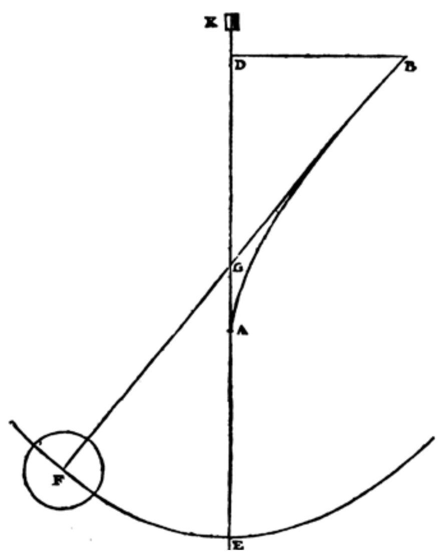
Almost 350 years later, Huygens' experiment has been carried out in the microscopic world, using two oscillators carved into a silicon microchip instead of pendulums. Each oscillator has a diameter of 40 thousandths of a millimeter, or 40,000 nanometers. These oscillators are so small and flexible that they vibrate from the light of a laser beam with a power a thousand times smaller than that of an ordinary laser pointer. Even more amazingly, the light exchanged between the oscillators plays the role of the wooden plank, synchronizing their vibrations.

The feat is the work of a team of researchers from Cornell University in the United States, led by the American physicist Michal Lipson. She was assisted by a Brazilian, Gustavo Wiederhecker, who has been a professor at the Institute of Physics, State University of Campinas (Unicamp), since 2011. Other groups had already built micro-oscillators synchronized through small mechanical connections. "We were the first to show that synchronization can be induced using only light," says Wiederhecker. "We thought it could be done, but it was not obvious that it would be possible."

More than a curiosity, the demonstration was published as the cover article of the journal Physical Review Letters, in the December 5, 2012, issue. The article suggests that these optical-mechanical micro-oscillators could become the basis of a new portable technology for high-precision timekeeping. Computers, cell phones and navigation systems all need precision timekeeping to work properly.

In general, these portable devices use the regular vibration of small quartz crystals—activated and synchronized using electrical signals—as clocks. Their accuracy is good, but the microelectronics industry is always looking for alter-

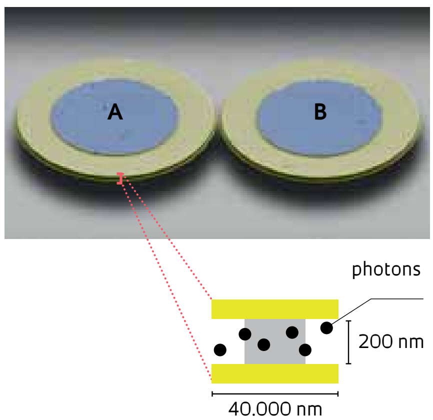
Drawing from the book Horologium oscillatorium, published in 1673, in which Christiaan Huygens describes the pendulum motion also observed at the edges of microscopic oscillators



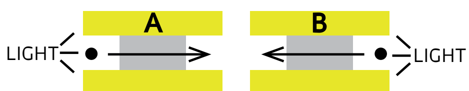

**INFOGRAPHIC** ANA PAULA CAMPOS **IMAGE** MIAN ZHANG / CORNELL NANOPHOTONICS GROUP **DRAWING** REPRODUCTION FROM *HOROLOGIUM OSCILLATORIUM*, 1673, BY CHRISTIAAN HUYGENS

# Laser interactions

Lightweight and flexible microscopic disks of silicon vibrate with the force applied by light

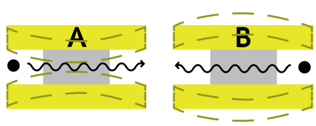



**1 AT REST**



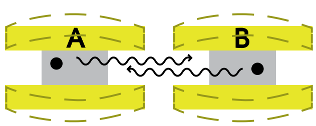

A continuous laser beam is aimed at the disks so that light with a specific wavelength enters the space between them

**2 OSCILLATION**




Light presses on the walls of the disks, forcing the space between them to grow and letting the light escape. Thus, the discs vibrate and emit light pulses

**3 SYNCHRONIZATION**




The light emitted by the pair of discs on the left enters the space between the pair of disks on the right, and vice versa, thereby synchronizing their vibrations

SOURCE GUSTAVO WIEDERHECKER - UNICAMP

natives because the crystals need to be manufactured separately from the silicon microchips and then soldered onto them, increasing the cost of production. However, the micro-oscillators developed by Lipson's team, made of silicon nitride, could be manufactured along with the rest of the internal structure of microchips, without additional cost. "Any factory in the world would be able to build the design," Wiederhecker points out.

The research began in 2008, when Wiederhecker, interested in investigating how light could be used to move parts of a microscopic mechanism in a silicon chip, obtained a post-doctorate position at Cornell under Lipson's supervision. By 2009, the Brazilian physicist had already published an article in the journal Nature as first author, showing for the first time that it was possible to manufacture a micro-structure that vibrates regularly when activated by light of a specific wavelength. In 2011, the team filed a patent for a filter based on this device, which was able to select telecommunications light signals of several wavelengths sent over optical fibers.

**PULSING IN UNISON**

In their latest work, the researchers produced dual oscillators. Each oscillator consists of a pair of superimposed disks separated by 0.2 millionths of a millimeter, or 200 nanometers (see infographic above). The disks vibrate when a laser beam of constant intensity and a wavelength able to enter the space between the discs is incident on them. When this happens, the particles of light travel around the edges of the discs and put pressure on their walls, forcing them apart. With the expansion of the space between the discs, the light escapes and the edges of the discs return to their original position. Then, more light from the laser enters the space, and the cycle begins again. The result is a pair of discs oscillating at a constant frequency, emitting light that pulses at the same frequency.

The physicists found that when these two oscillators were placed side by side, they could, under certain conditions, interact through these light pulses. At a certain vibration frequency, the flashing light emitted by one oscillator enters the space between the discs of the neighboring oscillator. "This blinking light forces the pair of discs on the right to vibrate at the frequency of the pair of discs on the left, and vice versa," explains Wiederhecker. "Eventually they come to an agreement and vibrate in sync, at the same intermediate frequency."

Wiederhecker built the first version of the micro-oscillator pair in 2010. The physicist Mian Zhang, also a member of Lipson's group, then developed a technique for turning the interaction between oscillators on and off, also using a laser beam.

According to Paulo Nussenzveig, a quantum optics expert at the University of São Paulo, the advantage of synchronization via light is that it allows interaction between a network of micro-oscillators through fiber optics, in which the oscillators can be placed as far apart as desired. "The quality and creativity of this work are significant," he says.

With a recently approved FAPESP Young Researcher grant, Wiederhecker hopes that his Unicamp laboratory will be able to perform these and other experiments with optical-mechanical devices by next year. He and physicist Thiago Alegre, his colleague at Unicamp, are mainly interested in investigating what happens when the oscillators are cooled to temperatures near absolute zero (-273.15 degrees Celsius) and the bizarre laws of quantum mechanics control their dynamics. "What does it mean to synchronize objects in the quantum world?" asks Wiederhecker. "This is something we're starting to explore." ■ **Igor Zolnerkevic**

Scientific article

ZHANG, M. *et al.* Synchronization of micromechanical oscillators using light. **Physical Review Letters**. v. 109, p. 233.906-10. Dec. 5, 2012.